Cassegrain Telescopes for Amateurs

By: Jeffrey D. Beish (Revised: 26 September 2014)

INTRODUCTION

In the late 1970's several of the local Amateur Telescope Makers (ATM) in Miami, Florida got together and began making telescopes. Up until then a 6-inch reflector or refractor was considered a fairly large telescope, but to own a 12.5" was considered heavy duty observing. So, we began with 12.5-inch mirrors and while some ground and polished their own mirrors some of us opted to have someone else do it. While the wide field observers would build shorter focal ratio Newtonian reflectors I chose a more complex design; the Classical Cassegrain telescope.

Reflecting telescopes are less expensive than refractors and when properly designed they can equal the high contrast images of a refractor without the associated chromatic aberration. Of course, the "roll-your-own" idea usually reduces this cost even further. But remember, this can vary greatly according to how large the aperture is. The larger the aperture -- the higher the cost. Don't forget you do have to account for the cost of the tools used in the total.

Even with the highest quality optics a reflecting telescope can be rendered nearly useless by tube currents, misaligned components, mirror stain, and a secondary mirror too large for the application of the instrument. The size of the secondary mirror and how it affects image contrast will be the main topic discussed here. Some fundamentals in Cassegrain design will be discussed along with methods of optimizing existing telescopes if one chooses not to build from the ground up. To determine the correct focal plane image diameter one consideration is the field lens in your collection of eyepieces. You may want to choose from the diameters of eyepieces you use and then go from there to determine the nominal image diameter at the focal plane.

Since most of our group either made their own or had a 12.5-inch f/4 mirror made, this would fit well with a Cassegrain design. So I laid out the ray tracing and requirements for a Cassegrain telescope for planetary observing. There are not many amateur telescope makers (ATM) today who build Cassegrain telescopes. However, there are interesting features of this design that makes it well worth investing the effort and money to build such an instrument. In my mind it was well worth the time and effort to build my first 12.5-inch f/4 – f/16 Classical Cassegrain and subsequently to upgrade it to a longer effective focal ratio telescope to increase the image contrast and also to get rid of some pesky mechanical problems.

Basic Classical Cassegrain Design

From several different types of Cassegrain telescopes I chose the Classical design with the parabaloid primary and convex hyperboloid secondary. Reading material on hand and Richard Berry's first ever issue of ***Telescope Making Magazine*** in the Fall of 1978, the first article, "Cassegrain Optical Systems," by: Dr. Richard A. Buchroeder, was all that was needed to get started. Also, a great read is Cassegrain Notes by Kenneth F. Novak that is now available on the Internet. The Classical system seemed to be the best choice due to less field curvature, availability for polishing tools and the fact that our local optician, Richard Fagin, had experience making them. From the available documents the following mathematical treatment was found and calculation began:

Cassegrain Equations:

$p = (F + b) / (X + 1)$, $p' = pX$, $B = p' - b$, $c = Dp / F + Bi / FX$,

Where: p = primary focus intercept point, p' = secondary to Cassegrain focus, F = primary focal length, X = secondary magnification, b = back focus, B = mirror separation, c = secondary clear aperture, i = final image size, D = primary diameter **[*Buchroeder*,** 1978**].**

NOTE: The separation between primary and secondary mirrors in a Classical Cassegrain reflector is critical. However, a small difference can be tolerated and is computed from: **(B) = 0.00248FR** ^{4} (if in centimeters then (**B**) **= 0.063 FR** ^{4}) **,** where **FR** is the focal ratio of the primary and the separation can be of 45% closer (**-B**) together or 55% further apart (**+B**) is tolerated[***Cox*** and ***Sinnott,*** 1976].

The minimum diameter for the Cassegrain secondary mirror: $c_{min} = Dp / F$. If the secondary mirror is already made the final image can be determined by: $i = X(cF - Dp) / B$.

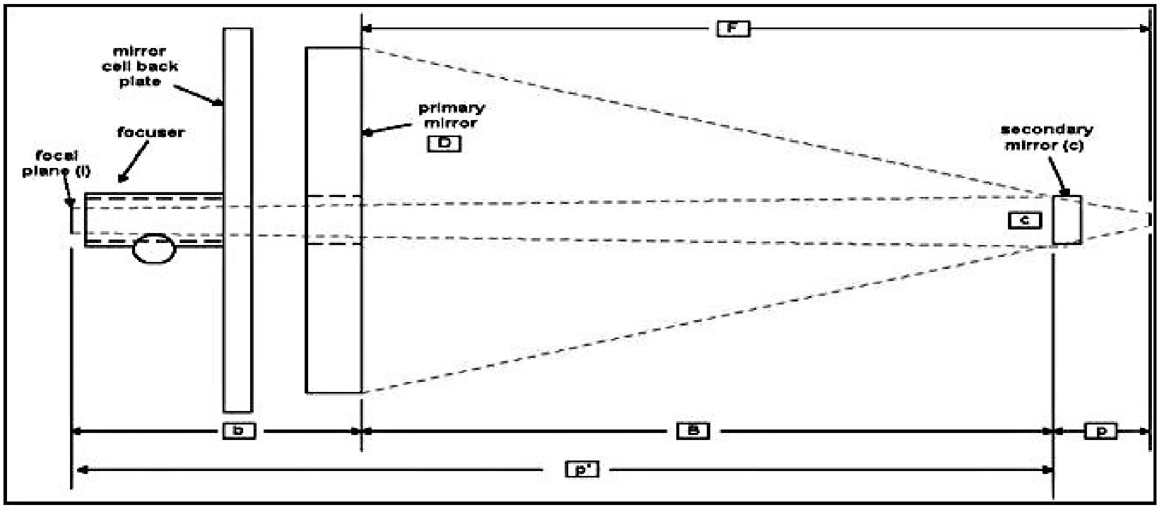

Figure 1. The Cassegrain telescope optical equations. Cassegrain Equations for description of terms in drawing: primary focus intercept point (*p*), secondary to Cassegrain focus (*p'*), primary focal length (*F*), secondary magnification (*X*), back focus (*b*), mirror separation (*B*), secondary clear aperture (*c*), final image size (*I*), primary diameter (*D*).

Baffles and Glare Stops

One factor in the design is the size and position of baffles and glare stops to prevent direct and indirect light from entering the eyepiece from the tube entrance and walls. Glare stops are often found in eyepieces, so, the placement and size can be determined by using the same equations as discussed herein for Cassegrain baffle tubes.

A baffle tube is usually placed in the primary mirror center hole in the typical Cassegrain design. In this case, the baffle tube is held in place by some solid insert in the primary mirror hole and actually touches the mirror glass. Stresses on the glass may happen and the attaching hardware can store unwanted heat. This author has found that attaching it to the mirror cell is best and it is possible to design the baffle tube to be adjustable. Adjusting the baffle tube attached to the mirror hole is difficult and may not stay in place for very long.

In determining the size of baffle tube it is easier to use materials available in local hardware stores. To the delight of many ATM there is an endless supply of tubes and gadgets found at a local hardware store or junkyard. Ordinary household plumbing fixtures, such as brass and PVC sink traps, come in handy and make perfect Cassegrain baffles. They come in several sizes from 1.25-inch to 2-inches in diameter and lengths of 6 to 18 inches. Also, sink traps can be fitted together to form even longer baffles if needed. I have used PVC and brass sink traps in the past with great results; however, PVC is lighter and easier to work with.

Cassegrain Baffle Tube Equations: The general equation for calculating the length of the baffle tube is:

$$L1 = (WB + Wb - cb - iB) / (c - i)$$

Where, **W** = baffle I.D., **B** = mirror separation, **b** = back focus, **K** = secondary holder outside diameter, **i** = final image size, **c** = clear secondary aperture and **V** = baffle tube outside diameter. [***Novak*** , 1978].

NOTE: Cassegrain Notes (***Novak*** , 1978) has a typo in the first baffle formula; where equation (**4**) has '**cB**' and should be '**cb**' in the third variable as shown in the above equation (**L1**).

If the walls of the tube are too thick then the baffle may be too long and block off light reflected from the primary to the secondary; therefore reducing illumination and contrast. Two additional equations are used to find the minimum baffle tube length (**L2**), so if the tube is too short then stray light will enter into the focal plane. The maximum baffle tube length (**L3**) that will not block off light reflected from the primary to the secondary. Here are two equations to test these conditions:

Minimum baffle tube length: $L2 = (WB + Wb - Kb - iB) / (K - i)$

Maximum baffle tube length: $L3 = F(K - V) / K$

If **L3** is shorter than **L1** or **L2** it stands to reason that the first two calculations produce a baffle tube that is too long. The way to shorten it is to either use a smaller inside diameter tube or one with thinner walls, or both. You can work with the above equations and test several tube diameters and wall thicknesses to make **L1** and/or **L2** less than **L3**.

It may be desirable to use a secondary mirror holder baffle; however, this may result in a slight increase in the secondary obstruction. To calculate the secondary holder baffle length (L4) from the mirror face:

secondary holder baffle length: $L4 = B(K - c) /D$

Where, **B** = mirror separation, **K** = secondary holder outside diameter, **c** = clear secondary aperture and **D** = primary diameter.

Ray tracing various tube diameters and lengths the positions for each glare stop was determined so to prevent light reflecting from baffle wall down the tube to the focal plane. Then the diameter for each stop has to be determined. In the glare stop equation listed below the sign to the '**Z**' term can be manipulated to calculate the diameter of each glare stop within the baffle tube. Term '**Z**' is the distance from behind the primary face to the position of the stop and usually presented in literature to calculate the rear glare stop. Changing the sign to minus (**-**) would put the stop in front of the primary face or somewhere along the baffle tube towards the secondary.

Also, the smooth material inside the baffle tube may cause light scatter in the optical path, so it can be lightly threaded in a lathe to rough up the material and after a light coat of flat black paint light scatter was significantly reduced. Flocking paper may also be applied to the insides of the tube, but remember that this will reduce the baffle tube ID. Typical flocking paper thickness is 0.025", so reduce the baffle tube I.D. by 0.05" and recalculate the length. **NOTE:** For aluminum tubing this web site has an ample supply of tube sizes.

Cassegrain Glare Stop Equations: $G = (Bi + Zi + cb - cZ) / (B + b)$

Where: **b** = back focus, **B**= mirror separation, **c** = secondary clear aperture, **i** = final image size, **G** = diameter of glare stop, **Z** = behind primary face [***Novak*** , 1978] [***Buchroeder*** , 1978].

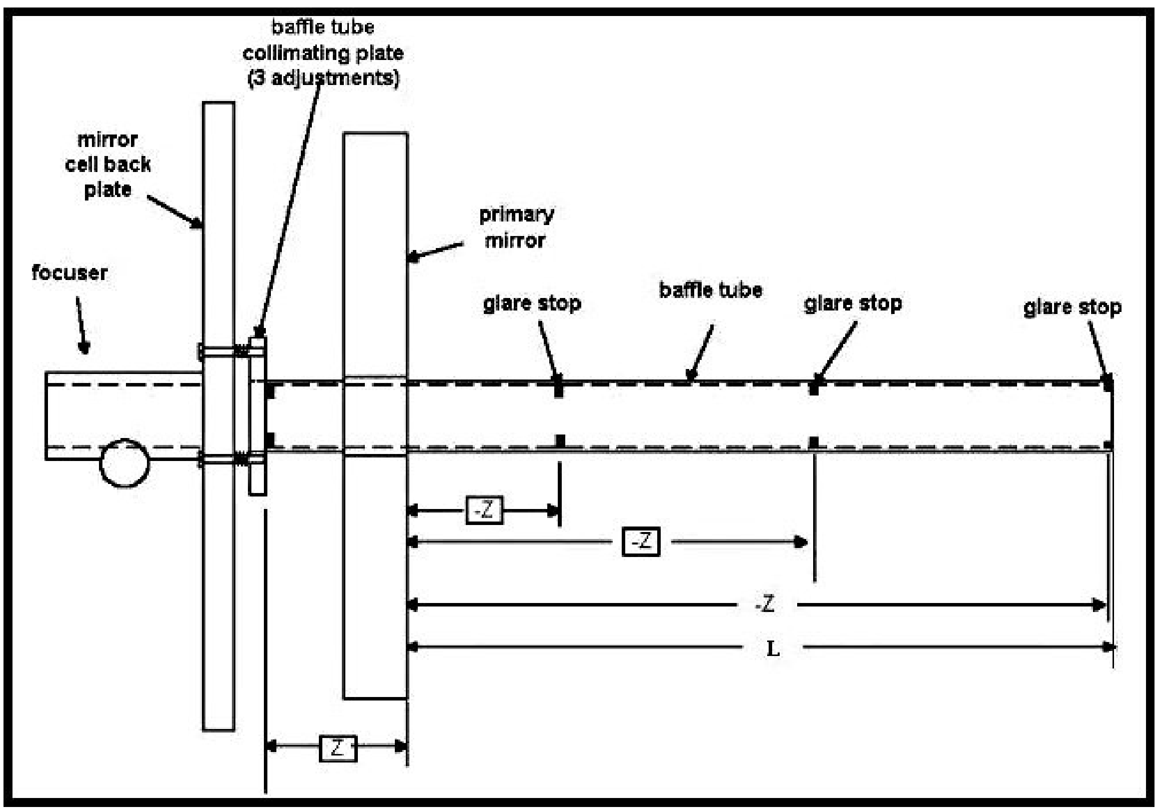

Figure 2. Cut away diagram of typical Cassegrain baffle and glare stop system. Term 'Z' is the distance from the primary mirror face to the glare stop with in the baffle tube. See equations below for calculating the Cassegrain optical system and baffles.

When you put this theoretical stuff in to practice you must make one more stop to check the baffle and glare stop system for proper operation. In other words, you want to look down the optical path from the focuser and see the secondary mirror only. You do not want to see direct or indirect light; therefore, to see if these glare stops are properly placed and sized then you need a mask for the end of the focuser the same diameter as the calculated image size. Otherwise when you peer down the optical path you may mistakenly look too close to the edge of the focuser and think the stops are not right.

A glare stop must be cut or machined smooth and circular. It would be wise for someone to employ standard machine shop devices to make these stops such as a metal cutting lathe. While not everyone has such machines available at home many ATMs or other hobbyists may help you with these simple projects or you may wish to take the job to a professional machinist. The holes should be cut or milled as smoothly as possible to avoid diffraction streaks or reflections.

There are various materials to make glare stops. The author found that brass is an excellent choice. Aluminum is another excellent choice. Once a baffle tube has been selected it is a mater of machining the stop to fit inside the tube with the correct inside diameter opening or aperture. When they are properly positioned within the tube a light coating of flat black paint will help secure the stops in place within the tube. Another glare stop can be positioned near the entry aperture of the focuser and up away from the eyepiece barrels. Some eyepieces have stops and some don't so it is wise to add this final glare stop near the eyepiece entrance and Cassegrain focus.

Remember, to check your baffles and glare stops you may want to machine an additional glare stop with the diameter of the linear image size to be placed at the focal plane for test purposes. After checking to see if the system has no direct light leaks around the secondary and you cannot see the walls of any of the baffles then remove this test stop and begin observing!

A Finished Design: 12.5-inch f/30 Classical Cassegrain

With a 12.5-inch, f/4 primary and the equations above we can find each parameter required for the mechanical design of the tube assembly. At the time all the necessary parts to build the tube assembly were available from Kenneth F. Novak & Co. Unfortunately, Kenneth passed away some years back and his company is no longer in business. The primary focal length worked out to be 51.5625 inches and a back focus of 10 inches.

To establish the back focus (**b**) we must measure the distance from the face of the primary mirror back through the mirror mount, back plate and the focuser to the focal plane. Novak's Cassegrain style 2" focuser is 4.25 inches high, when fully racked in, and given that the primary mirror is 2.125 inches thick, all that remains is the separation from the back of the mirror to the back plate. It is a good idea to start off with the collimation springs screwed in and then relieve the spring tension with a gap of around ½-inch. One may venture out to further; however, the mirror may shift or wobble if this gap is too wide. This will give plenty of room to collimate the primary later on.

After the primary mirror is installed and the back plate placed on a flat surface, a ruler can be inserted through the primary mirror hole to the flat surface so the distance from the primary face to the back of the plate can be found. My setup was 4.625 inches. Adding the 4.25-inch focuser (***FH***) the back focus distance would be a minimum of 4.625" + 4.25" or 8.875". Considering the 3-inch focuser travel (***Ft***) the back focus (***b***) was set so that the focal plane would be near the mid-way point from fully racked in and fully racked out positions, therefore adding 1.125" to the back focus so the total (**b**) was 10 inches. This would to accommodate the different eyepiece focal planes.

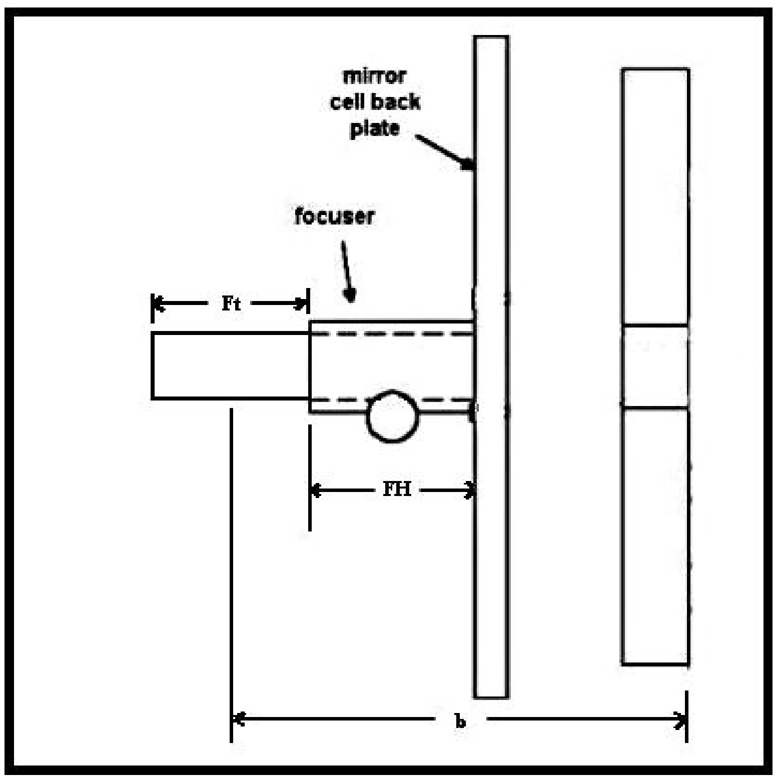

Figure 3. Cassegrain Focuser Placement where FH = 4.25", Ft = 3" and b = 10"

The secondary magnification for an f/30 Cassegrain is 7.5x, so the effective focal length (efl) will be: f/30 x D or 30 x 12.5 = 375" and the above equations yield:

$$p = (F + b) / (X + 1) = (51.5625 + 10) / (7.2727 + 1) = 7.4416$$

$$p' = pX = 7.4416 \times 7.2727 = 54.1209$$

B = p' – b = 54.1209 – 10 = 44.1209 (+0.3942 or -0.2857),

where (+B) = 0.55 x 0.00248 $(4)^4$ = 0.3492 and (-B) = 0.45 x 0.00248 $(4)^4$ = 0.2857

SELECTING THE SECONDARY MIRROR

So, we must select a mirror blank that is larger that the minimum (c_{min} = Dp / F = 12.5 x 7.4416 = 1.804”) and the actual diameter should be large enough to provide a practical image diameter, but not so large as to degrade the image contrast. Using my eyepiece collection the range of linear image sizes would be between 0.5 to 0.75 inches. Using the equations from the ***Basic Classical Cassegrain Design*** in the previous section we find the linear image diameter would be: ***i = X(cF – Dp) / B.***

Unlike readily available Newtonian secondary mirrors that come in standard sizes, blanks for Cassegrain secondary optics are harder to find and may vary from the standard sizes. When selecting the finished design one must choose a secondary mirror that is available from suppliers. I found the following secondary mirror blanks near the minimum diameter were: 1.83, 1.97 and 2 inches. To accommodate a star diagonal one must allow for the extra optical path length (OPL) of the particular diagonal. I used a mirror type diagonal that had 1.75-inch OPL that may have necessitated a back focus of 12 inches. This extra back focus did not change my design significantly, so the 1.97-inch secondary choice was okay with either a 10" or 12" back focus.

When selecting a secondary mirror and associated hardware one must consider the holder overlap rim and the thickness of the holder material. In this design I used Novak’s standard 26 gauge (0.0159”) thick secondary mirror holder with 0.03125” overlap rim, so the actual clear aperture of the secondary mirror is reduced by 0.0625 inches. One may wish to glue the mirror onto the holder without a rim or even the outer material that surrounds the mirror. For comprehensive instructions for gluing a Cassegrain Secondary see: http://www.fpi-protostar.com/ftp/cassinst02.pdf.

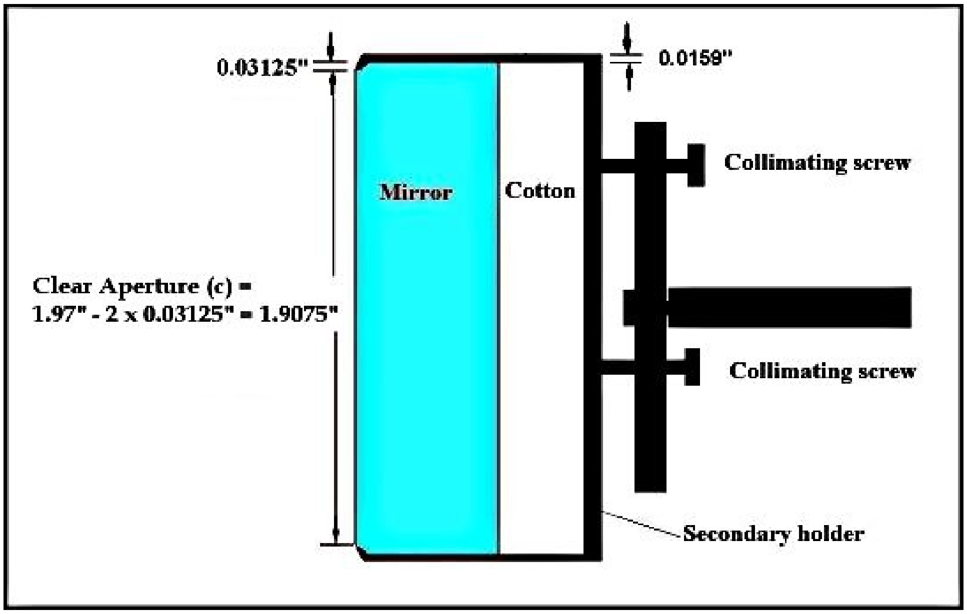

Figure 4. Cut away diagram of typical Cassegrain secondary and holder. Holder material is 0.0159" thick with a 0.03125" lip to secure secondary mirror into holder. The clear aperture (c) of the secondary mirror is the actual diameter of the mirror (C) – 2 x 0.03125" or C – 0.0625". Total obstruction is 1.97" + 2 x 0.0159" or 2.0018".

Given that the minimum diameter is 1.804" clear aperture the 1.83" blank (1.83 – 0.0625 = 1.7675") would not work, so I considered using a 1.97" blank. From the overlap rim the clear aperture of this selection would be: 1.97" – 0.0625" = 1.9075". The 1.97" blank would yield an image diameter (**i**):

$$i = 7.2727(1.9075 \times 51.5625 - 12.5 \times 7.4416) / 44.1209 = 0.8794"$$

The angular image of: $\mathbf{tan^{-1}\ (i/efl)} = \tan^{-1}(0.8794 / 375) = 0.134°$ or 484 seconds of arc.

When something blocks off some of the telescope entrance then light will flood or scatter into the dark rings and be scattered to the outer edge of the ring system and lower the image contrast. A poorly figured mirror will also produce an image of a star with a dull "Airy disc," a weak 1st ring, and very bright and broad second ring and so on, which decreases image contrast! Adding twice the holder material (2 x 0.0159"), the total obstruction of the primary mirror by this setup is 1.97 + 0.0316" or 2.0018"; so the obstruction ratio is 16.0% (2.0018" / 12.5").

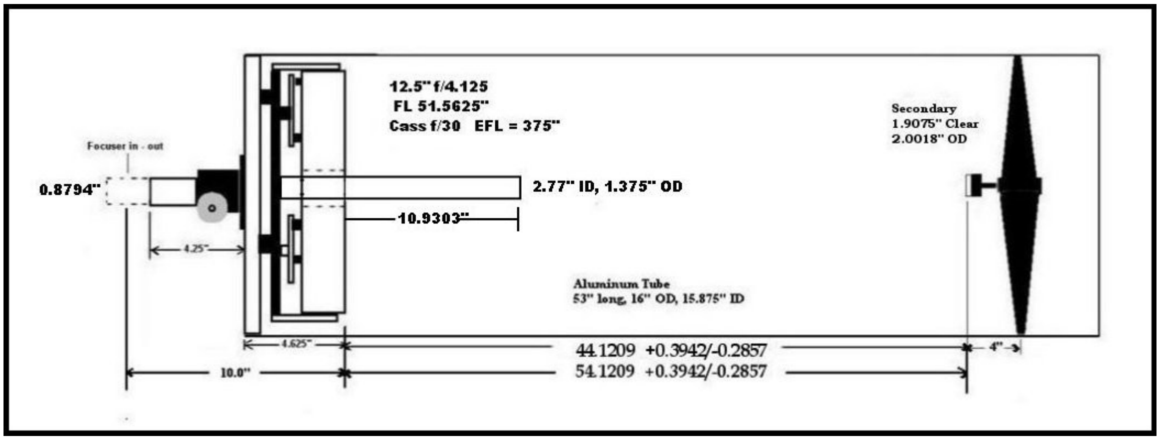

Figure 5. Cut away diagram of final results for the 12.5-inch f/4 – f/30 system: a 16% obstruction from the secondary mirror delivering 0.8794-inch linear image field (484 arcsec) with a contrast factor (CF) of 3.77 : 1, whereas a CF of 5.25 : 1 is an unobstructed system. . NOTE: contrast factor is discussed later in this article.

SELECTING THE PRIMARY BAFFLE TUBE

When considering the size and thickness of the primary baffle tube and the type of material to be used I wanted a light weight but stiff tube that would reduce direct light from the telescope entrance and any light scatter that is reflected from the inside of the tube and other components to the image field.

In the example for the 12.5" Cassegrain featured in the article we now can complete the three equations. First we consider the baffle tube inside diameter. This should be at least the linear image diameter of 0.8794" and we find that the nearest Schedule-80, 1-1/4" PVC sink trap will work well in this design. Now we have **W** = 1.277", **K** = 2.0018", a clear aperture secondary (**c**) = 1.9075" and **V** = 1.375", with a linear image of 0.8794" we can find length (**L**) of the primary baffle tube by:

L1 = (1.277 x 44.1209 + 1.277 x 10 – 1.9075 x 10 - 0.8794 x 44.1209) / (1.9075 – 0.8794) = 10.9303"
L2 = (1.277 x 44.1209 + 1.277 x 10 – 2.0018 x 10 - 0.8794 x 44.1209) / (2.0018 – 0.8794) = 9.1718"
L3 = 51.5625 (2.0018 – 1.375) / 2.0018 = 16.1452"

Since **L3** is longer than **L1** or **L2** then the baffle tube length will be **L1** or 10.9303". One could split the difference between **L1** and **L2** if the ray trace works out better.

The secondary holder baffle would be: L4 = 44.1209 (2.0018 -1.9075) / 12.5 = 0.3328"

Some eyepieces have glare stops and some don't so it is wise to add this final glare stop near the eyepiece entrance and Cassegrain focus. A glare stop must be cut or machined circular and as smoothly as possible to avoid diffraction spikes or reflections. The author found that brass or aluminum would be excellent choices. It would be wise for someone to employ standard machine shop devices, such as a metal cutting lathe or milling machine, to make these stops. While not everyone has such machines available at home many ATMs or other hobbyists may help you with these simple projects or you may wish to take the job to a professional machinist. In this design a 0.9744" diameter glare stop was placed 5.0" behind the primary:

$$G = (44.1209 \times 0.8794 + 4.0 \times 0.8794 + 1.9075 \times 10.0 - 1.9075 \times 4.0) / (44.1209 + 10) = 0.9934"$$

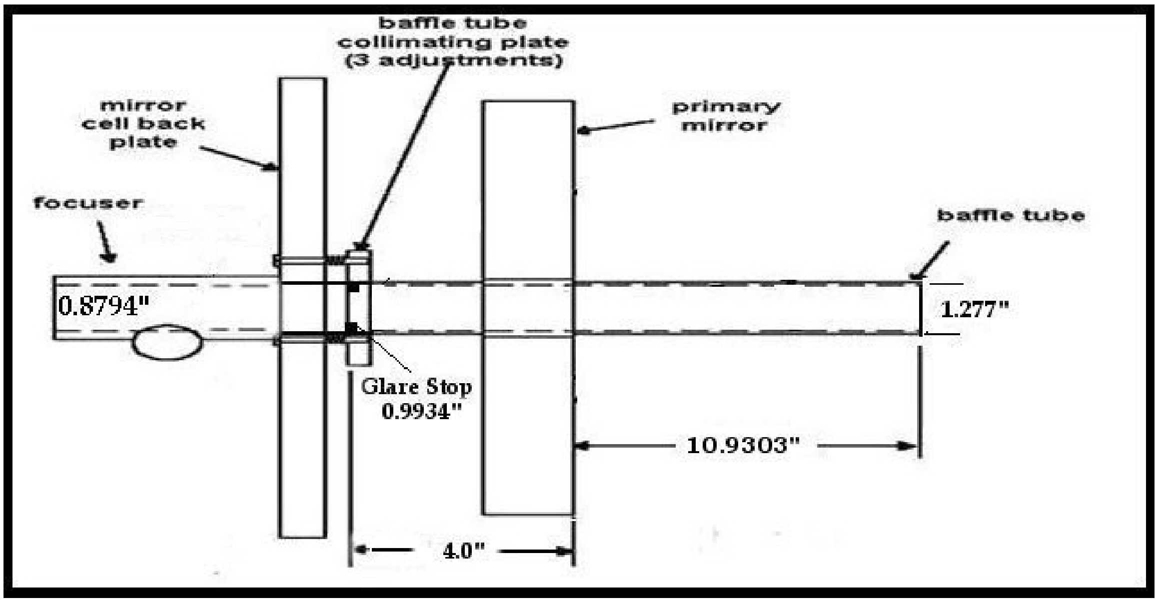

Figure 6. Cut away diagram of typical Cassegrain baffle and glare stop system. Term 'Z' is the distance from the primary mirror face to the glare stop with in the baffle tube. See equations below for calculating the Cassegrain optical system and baffles.

In my case I used a 1.25" PVC sink trap that had 1/16th-inch walls and proved to be light weight and stiff enough to remain in good shape for a long time. The tube was then glued to a ¼-inch thick, aluminum plate and that was mounted to the Cassegrain mirror cell and back plate using three long screws and springs to load the plate away from the back plate. The baffle tube can be collimated using this or a similar system.

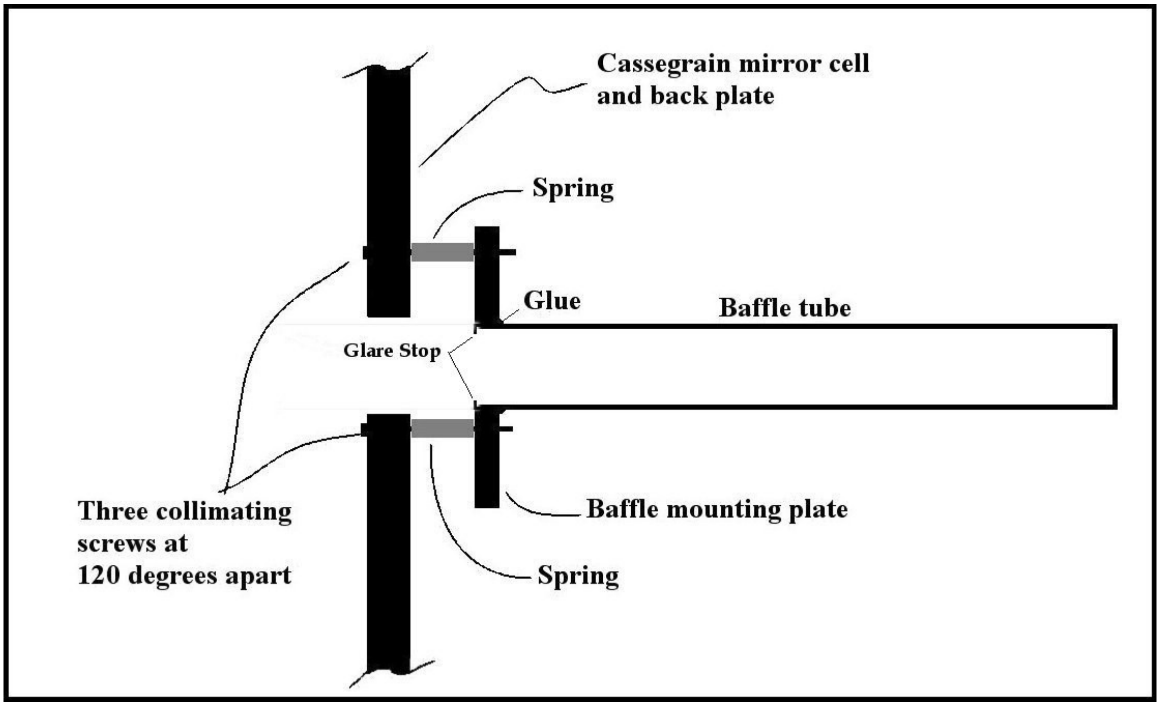

Figure 7. Cut away diagram of typical Cassegrain adjustable primary baffle tube. Using PVC sink trap tube glued to 0.25" thick aluminum plate three collimating screws are threaded into the plate from holes in the Cassegrain mirror cell and back plate forming a 120 degree triangle.

A 16” Classical Cassegrain Telescope

I had a 16-inch mirror that already had a hole in it and could have been a really neat telescope for observing planets. The design was on paper and it is a shame to let it go to waste. Some reader here may wish to use it as a guide to build a great planetary telescope – a 16-inch f/4 - f/50 Classical Cassegrain. The tube assembly was planned to be made from an 18-inch I.D. by 72-inch long thin wall (0.125) aluminum tube rolled and welded with aluminum rings for tube support, as was in the previous design. The rack & pinion focuser, primary cell, secondary holder, spider, and tube counterweight set.

The 16-inch primary was 3.125-inch thick and the distance from the primary face to the back plate surface of Novak’s Cassegrain mirror cell was found to be 6.625 inches. His Cassegrain style 2” focuser was 4.25 inches high when fully racked in, therefore, the back focus (b) would be a minimum of 6.625” + 4.25” or 10.875”. With a 3-inch focuser travel the back focus was set so that the focal plane would be near the mid-way point from fully racked in to out, so the back focus was set at 12 inches. A star diagonal would require an extra inch or two for the optical path length (OPL); however, even adding 2" would not change my design to any extent. This would result in:

p = (F + b) / (X + 1) = (64 + 12) / (12.5 + 1) = 5.6296”

p’ = pX = 5.6296 x 12.5 = 70.3704”

B = p’ – b = 70.3704 – 12 = 58.3704” (+0.3942’’ or -0.2857’’),

where (+B) = 0.55 x 0.00248 $(4)^4$ = 0.3492’’ and (-B) = 0.45 x 0.00248 $(4)^4$ = 0.2857’’

The minimum secondary diameter: c_{min} ***= Dp / F*** = 16 x 5.6296 = 1.4074”. From available sources anything smaller than 1.4” would not work, so I found the following secondary mirror blanks that may work: 1.5 and 1.61 inches. Eliminating a holder with shell and overlap rim the secondary is glued to the aluminum holder plate, so the clear aperture of a 1.5” secondary mirror would be 1.5”. The obstruction ratio is 9.4%. The linear image diameter would work out to be: i = 12.5 (1.5 x 64 – 16 x 5.6296) / 58.3704 = 1.269”.

The next consideration is the desired final linear image diameter to illuminate the eyepieces you intend on using with this telescope. Generally speaking, most eyepieces have field stops or diaphragms a short distance in front of the field lens in the barrel. Some do not, so the field stop will then be the diameter of the field lens. As a rule, for the critical planetary observer may want a small image, say, 0.5” to 0.75” for a small angular field. The magnifications that will most likely be used with this telescope would be 300x – 1000x. A check to determine the clear aperture of the secondary mirror diameter was calculated to be:

c = (16 x 5.6296) / 64 + (58.3704 x 1.269) / (64 x 12.5) = 1.5”

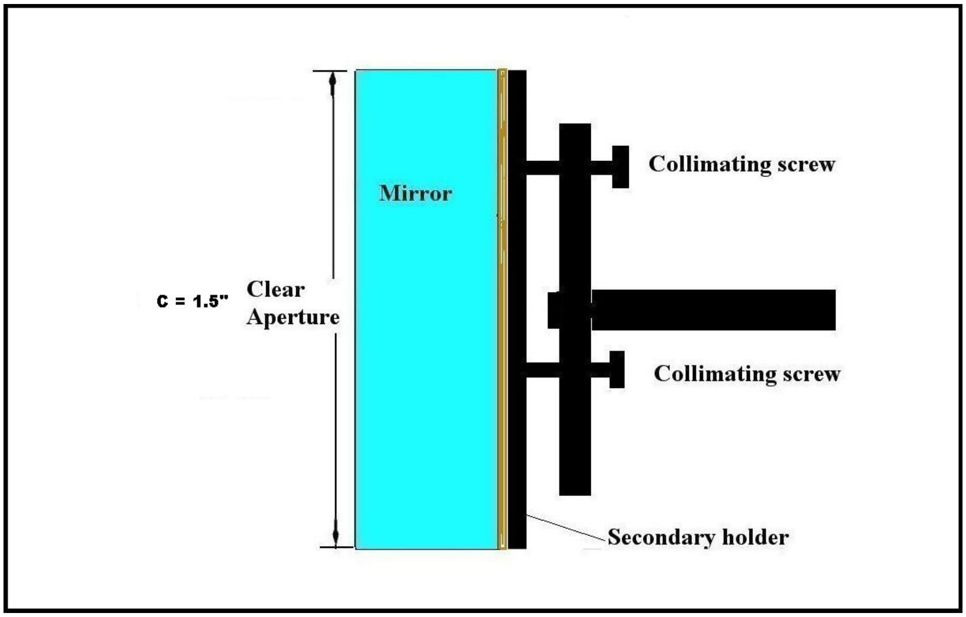

Figure 8. Cut away diagram of typical Cassegrain secondary and holder. Mirror glued to aluminum older plate. The clear aperture (C) of the secondary mirror is the actual diameter of the mirror (c) or 1.5”. Obstruction is 1.5 / 16 or 9.4%.

For the range of eyepieces on hand a 1” image is selected. The effective focal length (efl) will be: f/50 x D or 50 x 12.16 = 800” that will produce an angular image of: $\tan^{-1}$ (1/ 800) = 0.072° or 259 seconds of arc.

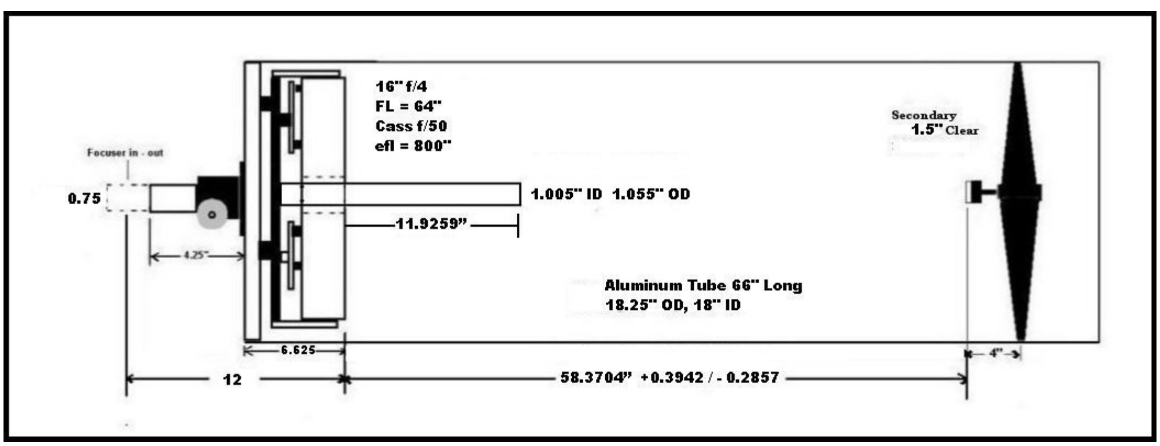

Figure 9. Cut away diagram of final results for the 16-inch f/4 – f/50 system: a 9.5% obstruction from the secondary mirror delivering 1-inch linear image field (193 arcsec) with a contrast factor (CF) of 4.50 : 1, whereas a CF of 5.25 : 1 is an unobstructed system.

Thus, with a 0.93" I.D. (1.055" OD) aluminum tube with 0.025" flocking then the ID = 1.005" we can find the length of the primary baffle tube by:

L1 = (1.005 x 58.3704 + 1.005 x 12 – 1.5 x 12 - 0.75 x 58.3704) / (1.5 – 0.75) = 11.9259"
L2 = (1.005 x 58.3704 + 1.005 x 12 – 1.5 x 12 - 0.75 x 58.3704) / (1.5 – 0.75) = 11.9259"
L3 = 50 (1.5 – 1.125) / 1.5 = 16"

The glare stop near the eyepiece entrance:

G = (58.3704 x 0.75 + 6.0 x 0.75 + 1.5 x 12 – 1.5 x 6.0) / (58.37048 + 12) = 0.8139"

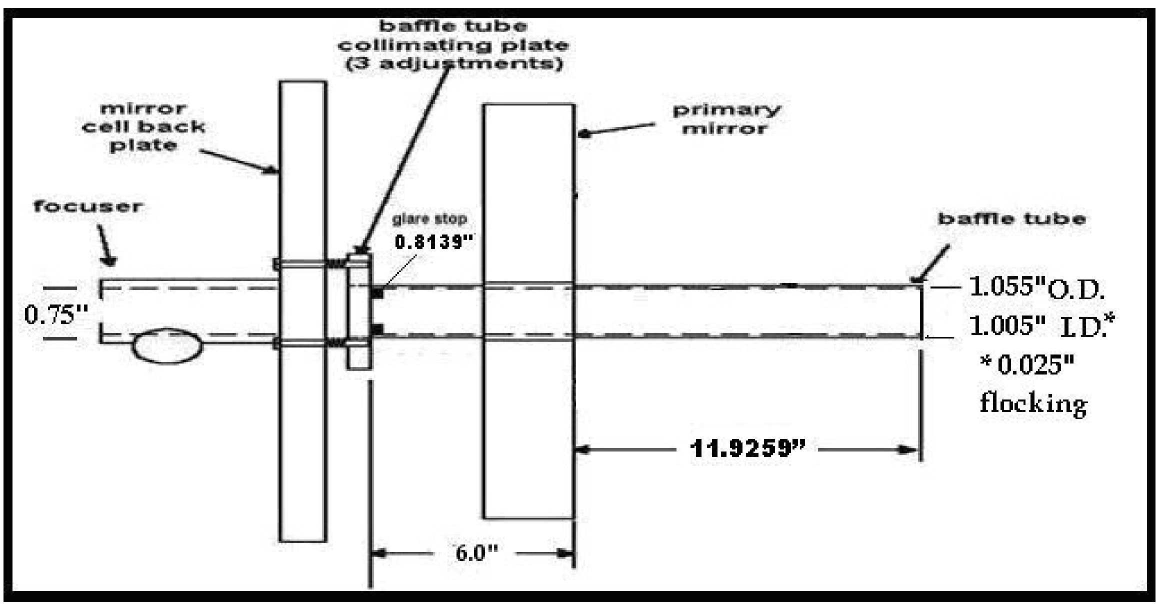

Figure 10. Cut away diagram of typical Cassegrain baffle and glare stop system. Term 'Z' is the distance from the primary mirror face to the glare stop with in the baffle tube. See equations below for calculating the Cassegrain optical system and baffles.

A LITTLE ABOUT APERTURE AND FOCAL LENGTH

In the early stages of designing this telescope I discovered several flaws that rendered it less efficient than at first thought. First, information of such designs was scarce and from the few commercial systems advertised in magazines my initial Cassegrain focal ratio (**cfr**) was arbitrarily set to f/16. Later, after more information was published, it became clear that a longer focal ratio would have been a better choice. First, some basic considerations and then a discussion on improvements.

It is no secret among amateur telescope makers (ATM) that the larger the aperture the more light the instrument gathers and the higher the resolution will be. Resolution is determined solely by the aperture and is often confused with image quality or a loss in contrast. The choice for those primarily interested in "deep sky" observing is usually a fast focal ratio or Richest Field Newtonian (f/4 to f/5). Planetary work requires a large image scale usually provided by the standard (f/7 to f/8) or long focus Newtonian (f/10 to f/12) or a Classical Cassegrain (f/16 – f/75). The focal ratio (f/#) is the focal length divided by the aperture.

Also, don't believe those who warn us to stay away from faster focal ratio telescopes. Faster mirrors are more difficult to figure, yes; however, no one says they are impossible. There are several opticians around this country who can figure excellent f/3's and f/4's. We often meet two types of people who do not like to figure fast mirrors; first, those who can't, and second, those making mirrors for planetary observers who need a longer focal length to increase the image scale. However, fast or short focal ratio reflecting telescopes requires a larger secondary and produces a smaller coma free field than the slower or longer focal ratio instruments. This will be discussed later. As a point of interest, the light gathering power of a mirror depends on its square area and is calculated simply by:

$A = \pi r^2$, where **A** is the area of the mirror, π is 3.14159, **r** is the radius of the mirror.

An example of the loss in light gathering caused by a 3-inch secondary on an 8-inch primary mirror, e.g., $r_{sec} = 1.5$ and $r_{prim} = 4$:

$$A_{sec} = \pi\, 1.5^2 = 7.1, \text{ and } A_{prim} = \pi\, 4^2 = 50.2$$

Dividing the square area of the secondary by the square area of the primary yields the percent of loss in light gathering power:

$$loss = A_{sec} / A_{prim} = 7.1 / 50.2 = 0.14 \text{ or } 14\%$$

Before going any further an understanding of several aspects of the human eye needs to be addressed. After all, in the final analysis the human eye is the ultimate test instrument to judge telescope image quality. It takes a long period of time observing a full range of astronomical objects in various atmospheric conditions and weather to fully test a particular telescope. Changes in design and component placement are bound to occur, so, to minimize this we should consider the individual's physical constraints -- such as age, how much they are willing to invest, their astronomical interest and conditions of the eyes.

THE OBSERVER'S EYE

It is commonly known the pupils of our eyes may open as much as 7mm, even 8mm, after we have been in complete darkness for twenty or thirty minutes. While this may be true when we are young, remember; as we grow older our pupils do not open as wide and generally by the age of 45 the eye may only open to around 5mm. So, we have the first design constraint to work from -- the maximum opening, or aperture of our eye pupil. Also, eye fatigue or observing bright objects in the telescope will cause a smaller pupil opening.

Generally speaking, most eyepieces have field stops or diaphragms a short distance in front of the field lens in the barrel. Some don't, so, the field stop will then be the diameter of the field lens. Usually, field lenses in 1.25-inch barrel eyepieces are 0.75 to 1.0 inch in diameter. In two-inch barrel eyepieces the field lens is usually 1.50 to 1.75 inches (considering the field lens cell and barrel thickness).

As a rule, for most casual planetary and deep sky observers a linear image size between 0.5 to 0.75 inches will do fine. The critical planetary observer may want a small image, say, and 0.25 to 0.375 inches for a small angular field. The critical deep sky observer with two-inch eyepieces may want a 1.0 to 1.5-inch image for a wide angular field. It makes no sense to use eyepieces that produces a larger exit pupil than your eye can accommodate and this should be one of the limiting factors in determining the secondary size. Since the longer focal length Cassegrain will be used for planetary work therefore we usually use magnifications from 250x – 1,000x, so expect the exit pupil to be in the range of 0.5mm to 2mm for 10" to 16" telescopes.

When looking through the telescope eyepiece we actually see the magnified image of the primary mirror and the focal plane is located a short distance in front of the field lens when the image is in focus. The image is projected onto our eye a short distance from the eyepiece "eye lens" and this point is called the exit pupil (**EP**). To determine the lowest effective magnification for our instrument divide the aperture by the exit pupil, this in essence is the observer's fully opened eye pupil. This can be found by:

M = D / EP, where **M** is the magnification, **D** is the aperture, and **EP** is exit pupil.

By dividing the telescope focal length by this magnification gives us the longest focal length eyepiece you will need. With the lowest effective magnification that produces a 5mm or 7mm EP you can select the linear image size of the focal plane. The size and types of eyepieces generally dictate this on hand.

For example, consider a person with a collection of eyepieces with field lenses of 0.75-inches (19mm) and an assumed dark-adapted pupil diameter of 8mm. His or her telescope may have an aperture of 10 inches (254 mm) with a focal length (FL) of 60-inches (1524mm), the lowest effective magnification will be:

$$M = 254 / 8 \text{ or } 31.75x.$$

In this example a 48mm eyepiece would be the longest focal length eyepiece you would need (1524 / 31.75 = 48x).

IMAGE CONTRAST

Since a Classical Cassegrain requires a secondary mirror to reflect the primary image back through the primary mirror it has to be positioned somewhere in the optical path. This causes an obstruction in the optical path and reduces some of the light gathering power of the primary. More important this obstruction adversely effects image contrast. If we scatter stray light throughout the image it makes the dark areas of the object brighter and the bright areas darker, therefore, a loss in image contrast. What really happens is the obstruction of the secondary tends to remove light energy from the Airy disc and distributes it among the dark and bright rings in the diffraction disc of a stellar image or many points in an extend image.

Image contrast, as perceived by our eye, is the difference in brightness or intensity between various parts of the telescopic image, i.e., and a star against the background sky. A simple formula for calculating contrast is as follows:

$$\mathbf{c = (b2 - b1) / b2},$$

where **b1** and **b2** are the intensities levels or brightness measured in candle power/meter squared (cd/m^2) of two areas of the object and c is the contrast.

For example, Jupiter has a surface brightness of around 600 cd/m^2 for lighter areas. If we compare a dark belt, of 300 cd/m^2, then the contrast between these areas would be: c = (600 - 300)/600 = 0.5 or 50%. If we scatter light from the bright area, say 50 cd/m^2, and add it to the dark belt then the contrast between the two becomes: c = (550 - 350)/550 or 0.36 or 36%. A relatively small amount of scatter may cause a significant decrease in image contrast. The Earth's daylight sky brightness has been measured at about 8000 cd/m^2 [***Chapman et al*** , 1980].

An image of a star formed by a perfect lens or mirror is seen as a spot of light surrounded by several bright rings and dark spaces separating the rings. We theorize that 83.78 of the light falls in the central spot, or "Airy Disc," 7.21% in the first bright ring, 2.77% in the second, and 1.47% in the third and forth rings [***Hurlburt*** , 1963, and ***Johnson*** , 1964, and ***Stoltzmann*** , 1983].

When something blocks off some of the telescope entrance then light will flood or scatter into the dark rings and be scattered to the outer edge of the ring system and lower the image contrast. A poorly figured mirror will also produce an image of a star with a dull "Airy disc," a weak 1st ring, and very bright and broad second ring and so on, which decreases image contrast! From the graphs and tables published in the referenced articles on Newtonian improvements in the J***ournal of the Association of Lunar and Planetary Observers (J.A.L.P.O.)*** a general equation can be arrived approximating the "contrast factor" value for your system (See Table I). I derived an equation from tables published in the referenced articles and came up with an equation:

$$CF = 5.25 - 5.1x - 34.1x^2 + 51.1x^3 ,$$

where **x** is the obstruction ratio or secondary/primary diameters.

Table I. Values for obstruction and contrast factor. The left-hand column is obstructions in percentage of secondary to primary mirror in linear diameters. Next column gives the central spot energy percentage, next the energy in the rings and then the contrast factor values taken from the reference text.

Obstruction	Central Spot	Rings	Contrast
RATIO (%)	ENERGY (%)	ENERGY (%)	FACTOR
0	84	16	5.25
10	82	18	4.45
20	76	24	3.27
30	68	32	2.03
40	58	42	1.02
50	48	52	0.56

An image of a planet or extended deep sky object may appear sharp and bright, but, barley show any surface details in a telescope with 30% obstruction. This same telescope will show very fine surface details and give refractor quality high contrast images in a telescope if the secondary obstruction is reduced to, say, 12%. This can be accomplished without perceptible vignette of the image.

DISCUSSION

After reading more informative articles on this design and learning while modifying my original design the improvements made were striking. This telescope started off with a heavy tube made from low inertial material that would seem to take forever to stabilize with the ambient air and with image contrast was less than desirable for planetary viewing. The focal ratio was increased from f/16.5 to f/30 and the back focus shortened, therefore reducing the required secondary diameter and increasing the system focal length that helped the depth of field so I could use longer focal length eyepieces.

The original tube assembly was made from a commercially available 16” x 53” x ¼” fiberglass tube weight around 34 pounds. That was replaced by a 16-inch I.D. by 53" long thin wall (0.060) aluminum tube rolled and welded by a local business weighing only 16 pounds. I used the end ring from the fiberglass tube that is used at the secondary end to supports the tube. This ring also helps conform the tube and make centering of the spider and mirror cell very easy. The entire tube is lined with 3/16th-inch cork purchased from a local hardware store and glued in place then painted flat black and also provides a rough finish to reduce light scatter. The rack & pinion focuser, primary cell, secondary holder, spider, and tube counterweight set were purchased from Kenneth F. Novak & Co. The 12.5-inch diameter (51.5625-inch focal length) primary and 1.97-inch secondary for this telescope were made by our local optician, Richard Fagin.

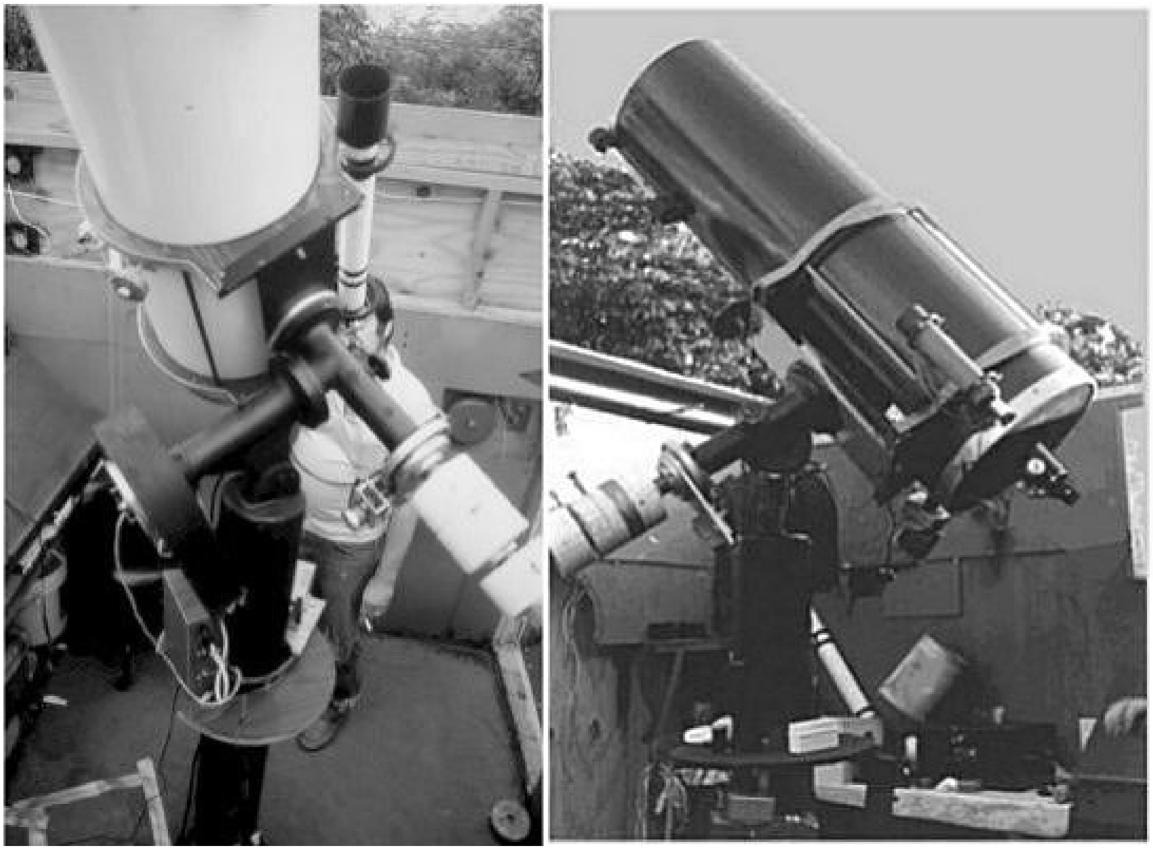

Figure 11. LEFT: My first 12.5-inch f/16.5 Classical Cassegrain telescope design and RIGHT: modified to f/30 with cork-lined, black aluminum tube.

With the tube straight up the focuser stands 3.5 feet (42 inches) from the ground and requires a regular chair to observe with. Using a Park's German equatorial mount purchased back in the late 1970's, this German mount has 1.5-inch chromium steel shafts with two bearing each axis to provide stability and weight approximately 150 pounds [***Beish*** , 1999 and ***Beish*** , 2000]. The center of gravity is about 13 inches from the primary end. The 18" long saddle completely a wooden system reinforced by aluminum bands.

The size of the secondary mirror in a reflector causes lots of arguments among amateur telescope makers (ATM) and much of it comes from books that may confuse people or in effect establish hard and fast rules than are misunderstood. Sometimes, these books only define the extreme limits of the telescope optics and omit practical limits. Equations are published that are usually correct and one only has to find the necessary variables to insert in equation to come up with a reasonable design.

One variable is the illuminated field or finally image diameter at the focuser a short distance past the focuser. How much of a field do we need to produce an image of a planet or a deep sky object of comparable size? This variable is one thing the designer has control over, so this may be a start in our design planning.

A primary baffle is necessary in a Cassegrain telescope to shield the focal plane, therefore your eye, from direct light from the telescope entrance and/or stray light reflected from the telescope tube walls or other components. The ability to adjust or collimate the baffle tube is quite handy, especially when first assembling the telescope for the first time. It is difficult to make sure the secondary mirror is centered in the optical path and if the baffle tube is attached to the primary hole, in the usual way, then there is really no way to know if the tube is aligned correctly in the mirror hole. If the baffle tube is separated from the actual primary mirror and a way to collimate it to he secondary mirror holder then we will be happy campers when it comes time to first assemble the telescope and make sure the optics are centered and collimated.

A small program (Cass.zip) to compute the optical parameters of a Classical Cassegrain Reflector.

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